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A Practical Commercial Output-Transformerless Amplifier*

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SINCE THE appearance of the author's first paper on the subject of output-transformerless amplifiers, he has had numerous inquiries for further details regarding the amplifier which he described.[1] A program of further work was instituted with a view to producing a practical, commercial version of this basic amplifier design. The present paper will describe the results.

BASIC DESIGN OF THE AMPLIFIER

To review the basic design of the amplifier, reference should be made to Fig. 1. A pentode tube, V_1, is operated as a high-gain voltage amplifier and is directly coupled to the phase-splitter tube, V_2. The cathode-load resistor of V_2 is returned to ground through the load, which may be the 16-ohm voice coil of a conventional loudspeaker. Signal voltage developed across the plate-load resistor of V_2 is applied between grid and plate of the output tube V_3. Likewise, signal voltage 180° out of phase, developed across the cathode-load resistor of V_2, is applied between grid and plate of output tube V_4.

The Output Stage

The output tubes are connected in series and biased for class B_1 operation. The output load is connected with its "high" side to the cathode of V_3 and the plate of V_4 and its "low" side to ground. Each of the output tubes has its own power supply, consisting simply of a metallic rectifier, X, and a capacitor, C. Due to the balanced nature of the output circuit, no dc flows through the load.

Feedback Arrangements

The potentiometer in shunt with the load has its arm in the cathode circuit of the voltage-amplifier tube, V_1. When the arm of the potentiometer is at ground, there is no over-all negative feedback and the full gain of the amplifier is obtained. With the arm at the high side of the load, there is 100% negative feedback, and the gain of the amplifier is essentially unity. Because of the minimum number of phase-shifting components in this amplifier, large amounts of negative feedback may be utilized. The writer has constructed amplifiers of this type with as much as 60 db of feedback without any evidence of instability.

Driving Voltage

In this circuit, the output tubes are working as cathode followers and thus require large driving voltages from the phase-splitter tube. With this type of phase-splitter, the signal voltage across the plate and cathode resistors is essentially of the same magnitude as the input voltage to the tube. Normally, this would require a large voltage output from the voltage-amplifier tube. Fortunately, because the speaker load is also in the input circuit of the phase-splitter tube and in the correct sense to provide positive feedback, a much lower voltage suffices. In fact, the signal voltage to the input of the phase-splitter tube need not be much greater than the fixed bias of the power tubes, for maximum output.

Positive and Negative Feedback

A feature of this amplifier, as can be seen in Fig. 1, is that the output load is connected to the input circuits of all the tubes used in the amplifier for the purpose of obtaining both positive and negative feedback. This has been accomplished without the use of any reactive components (which might produce undesirable phase shifts) other than the load itself.

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[1] Julius Futterman, "An Output-Transformerless Power Amplifier," JOURNAL OF THE AUDIO ENGINEERING SOCIETY, 2, 252–6 (October 1954).

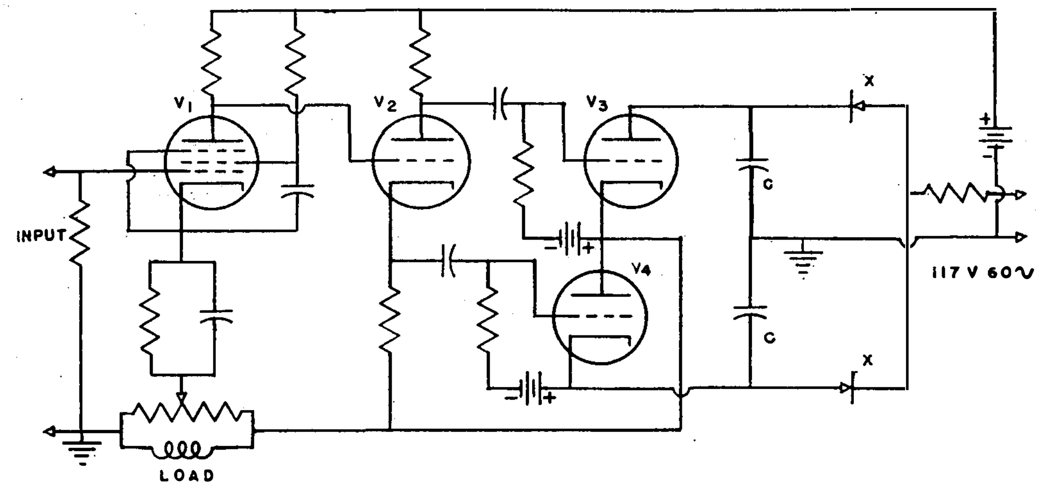

FIG. 1. Basic schematic of the output-transformerless power amplifier.

For large ratios of overall negative feedback, the gain of the amplifier should be high over the frequency range of interest. Most of the gain is obtained in the voltage-amplifier stage. Using a 6BA8 tube with a plate load resistor of 1.8 megohms, a voltage gain of 1200 can be realized. The overall gain of the phase-splitter and output tubes may be greater or less than unity, depending on the number and type of tubes used in the output stage and also on the impedance of the output load.

Power-Supply Arrangements

To make it possible to obtain large amounts of power from a class B_1 output stage, the regulation of its power supply must be good. This necessitates a low-impedance supply. In this circuit, the author felt that the most practical way of accomplishing this was to use a separate power supply for each half of the output stage. Because of the large amount of negative feedback available, the power supplies for the output stage are extremely simple, each consisting of a metallic rectifier and capacitor. If, without any feedback, the ripple voltage across the voice coil were 1 volt, then, with 60 db of feedback, the ripple would be reduced to 1 millivolt. In fact, the amplifier may be considered as an electronic filter for these two power supplies.

One objection to the original amplifier was that it was not isolated from the ac line. This was considered serious, because, when the amplifier was used with auxiliary line-operated equipment, there was always a shock hazard present. To remedy this fault, a special power transformer was designed for use with the present amplifier.

THE NEW AMPLIFIER

Figure 2 is the circuit of the complete power amplifier, as finally developed.[2] Figures 3 and 4 are photographs of the amplifier. A 6BA8 tube is employed as a combined voltage amplifier and phase-splitter. Ten type 12B4A tubes are used in the output stage. The power rectifiers are either 1N158 germanium rectifiers (shown on the schematic) or Radio Receptor type 6S2 selenium rectifiers, with a rating of 500 ma at 156 volts. The power transformer is a special low-impedance unit in which both the primary and the 130-volt winding that supplies plate current for the power tubes have a dc resistance of less than 1.5 ohms. This is essential, so that the large current demands made on the power supply when peaks of program material are handled can be met.

Surge-Limiting Resistors

To prevent the initial surge of charging current through the 600-mfd filter capacitors from damaging the rectifiers when the amplifier is first turned on, a surge-limiting resistor of 300 ohms is connected in series with the rectifiers. The function of the Sigma Type 11F relay is to short out this resistor when the voltage across the filter capacitor builds up to a value high enough to operate the relay. This usually takes approximately 2 seconds.

Series Heaters and Bias Arrangements

It will be noticed that the heaters of the five "lower" 12B4A tubes are connected in series. This is done so that the 31.5 volts required for heater voltage can also be used for grid bias. Fixed bias of approximately –25 volts for these tubes is developed by the selenium rectifier, Radio Receptor Type 4Y1. Grid bias for the "upper" output tubes is obtained

[2] Since this paper was delivered, Mr. Futterman has been granted U. S. Patent No. 2,773,136 (date of issue, December 4, 1956), covering features of this amplifier.

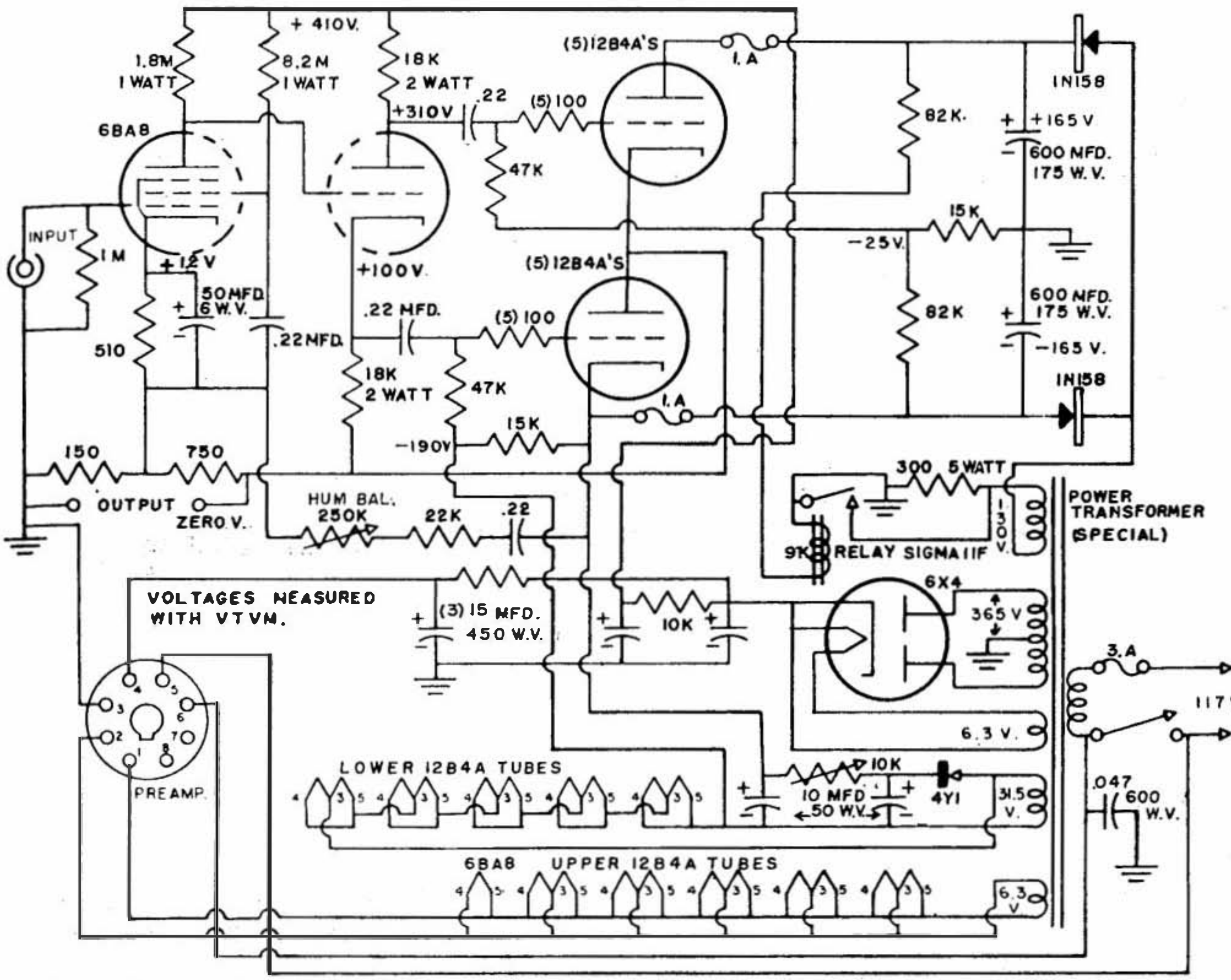

FIG. 2. Complete schematic of the OTL power amplifier which uses ten type 12B4A miniature tubes in the output stage.

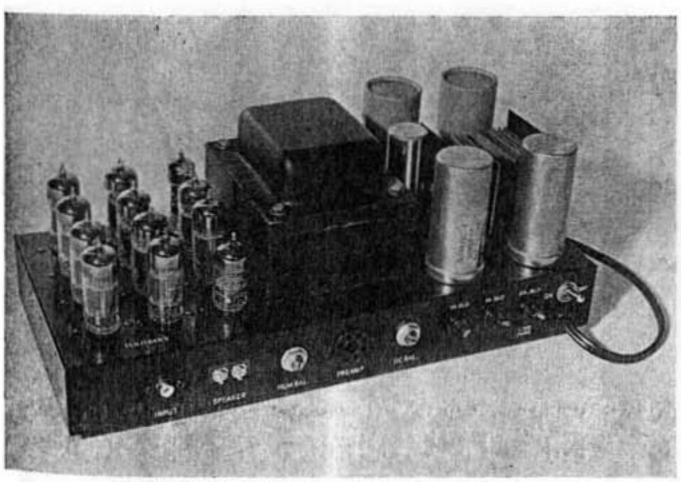

FIG. 3. OTL power amplifier constructed on a 13½ in. × 6 in. × 1¾ in. chassis. (The schematic is shown in Fig. 2.) Note the logical layout: Heat-producing components are separated from the electrolytic capacitors and power rectifiers.

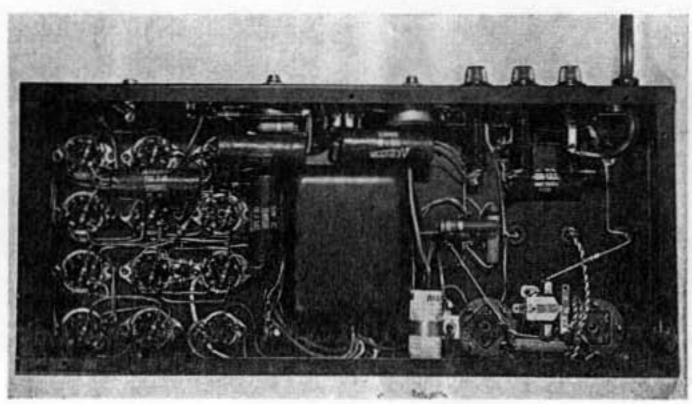

FIG. 4. Bottom view of the output-transformerless amplifier of Fig. 3.

from the voltage divider (consisting of an 82K resistor and a 15K resistor) connected across the power supply that is used for the lower output tubes. The 10K potentiometer is used to adjust the bias on the lower 12B4A tubes, so that there is no dc in the speaker voice coil. The quiescent plate current of the output stage may be anywhere between 50 and 100 ma, depending on the characteristics of the individual 12B4A tubes. One advantage of using ten power tubes is that the 10K potentiometer can be set so that the grid bias on the lower 12B4A tubes is equal to that on the upper 12B4A tubes. With a milliammeter in series with the speaker voice coil, the power tubes can then be interchanged to secure a minimum current reading on the meter. A precise zero adjustment can then be made with the potentiometer. The advantage of this procedure is that clipping will occur simultaneously on both positive and negative peaks at the overload point of the output signal.

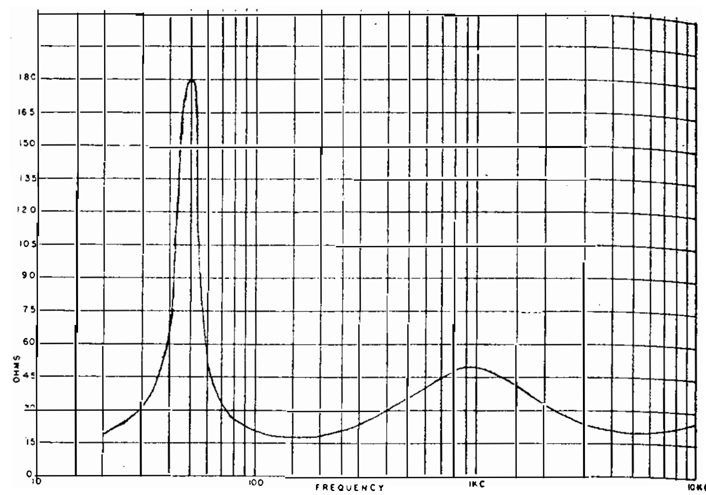

Fig. 5. Measured impedance curve of the author's LC-1A loudspeaker in 10-cu-ft infinite baffle.

Preamplifier Plate and Heater Voltage

The 6X4 rectifier tube supplies plate voltage for the 6BA8 tube and also for an external preamplifier. Heater voltage for the preamplifier is also provided. These voltages are available at the octal socket indicated in the schematic. The voltage gain of the amplifier is 6, so that it can easily be driven to full output by most preamplifiers.

Power-Output Capabilities of the Amplifier

We have not, thus far, mentioned the power output capabilities of the amplifier; this has been deliberate. Power amplifiers are usually rated with a fixed impedance load. However, as is well known, a loudspeaker rated at, say 16 ohms will vary considerably in impedance over the audio-frequency spectrum. Figure 5 is the measured impedance curve of the writer's own speaker system, which consists of an RCA Type LC-1A loudspeaker mounted in a 10-cu-ft infinite baffle. Note that the impedance varies from a maximum of 180 ohms at the bass resonant frequency to a minimum of 18 ohms. This is a variation of 10:1. Power output at the overload point as a function of the load impedance is plotted in Fig. 6 for the OTL amplifier when germanium or selenium rectifiers are used. For comparison, a conventional 30-watt amplifier utilizing negative feedback is also shown. Figure 7 shows the power output in watts as a function of frequency for the two amplifiers when the speaker system of Fig. 5 is used. Note that the 30-watt conventional amplifier will overload at less than 6 watts at 50 cps, as compared to over 15 watts for the OTL amplifier. For normal home listening, even on live FM program material, the writer has never felt that his amplifier seemed lacking in output power. This has been confirmed by several of his friends who have built similar amplifiers and have used them with the so-called "low-efficiency," "high-fidelity" loudspeaker systems. The writer believes that the OTL amplifier described here, with a 16-ohm loudspeaker load, is definitely equal in performance to a conventional 30-watt amplifier when reproducing program material. Further, he is convinced that the OTL amplifier yields results which are definitely superior when a 32-ohm loudspeaker system is employed.

The foregoing has been brought out because the author feels strongly about the continuous race for higher and higher output in power amplifiers designed for high-fidelity home music systems. A few years ago, 30-watt amplifiers were considered excessive. Today, we see 50-, 70-, and even 100-watt amplifiers placed on the market to be sold as components for home music systems. One prominent manufacturer has a 70-watt amplifier on the market with what he claims is an exclusive feature—an automatic power monitor which reduces the output power of the amplifier so as to protect "expensive speakers" from "burning out." This, presumably, is a worthwhile feature and costs only a mere one hundred dollars more than the same company's "ordinary" amplifier, which puts out only 32 watts and is not supposed to be capable of burning out your speaker.

In the output-transformerless amplifier, output power is hard to come by. We find that our original 10-watt amplifier is more than adequate in our living room. The increased output of the present amplifier is a concession to the powers that be.

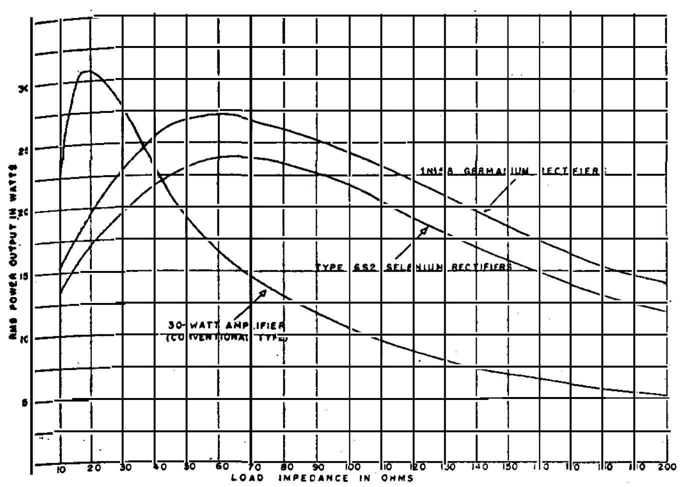

FIG. 6. Power output of output-transformerless amplifier at the overload point, plotted as a function of load impedance (when germanium and selenium rectifiers are used). Curve *A* represents the power output of a conventional 30-watt amplifier; curve *B*, the power output of the OTL amplifier with a 6S2 selenium rectifier; curve *C*, the output of the OTL amplifier when a 1N158 germanium is used.

Measurements

Measurements of frequency response, square-wave response, and harmonic distortion for the present amplifier are similar to those for the original amplifier and will not be repeated here. The reader is referred to the original paper.[1] Tests for intermodulation distortion were not made on the original amplifier but have been performed on the *present* amplifier, the necessary equipment having become available. Measured with a Measurements Corporation Model 31 IM analyzer, the distortion proves to be less than 0.1% from a 1-watt to a 10-watt level. From 10 watts to the point where clipping is noticeable on the scope (this is the point of maximum output indicated in Fig. 6), the distortion rises gradually to 0.3%. These figures include the residual intermodulation distortion of the analyzer, which is 0.1%. Consequently, we may say that there is no measurable distortion up to the 10-watt level.

SOME TIPS TO THE AMPLIFIER BUILDER

The amplifier is simple to construct and adjust. There are no "gimmicks." Resistors and capacitors should be checked wherever possible before being used. Tubes should be tested for gas and internal shorts. The "hum-balancing" potentiometer should be adjusted for minimum hum with no input to the amplifier. Your ear will have to be in the speaker for this adjustment.

In conclusion, it is the opinion of the writer that when the present output-transformerless amplifier is used with first-class associated equipment, it leaves nothing to be desired in the high-fidelity home installation.

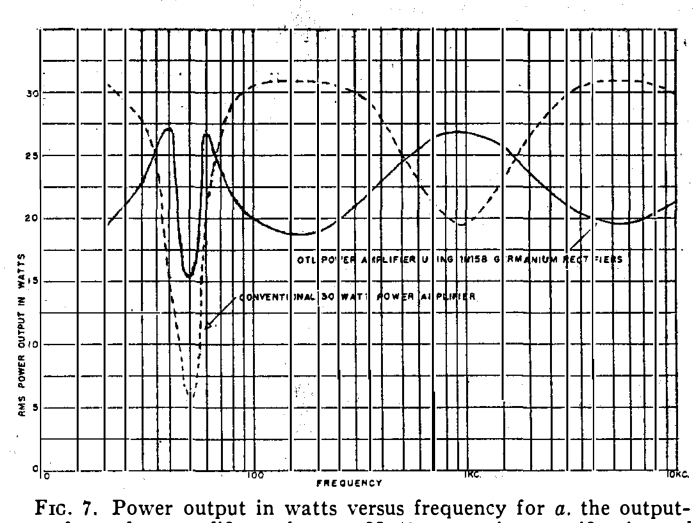

FIG. 7. Power output in watts versus frequency for *a*. the output-transformerless amplifier, when a 1N158 germanium rectifier is used (solid curve); *b*. a conventional 30-watt power amplifier (dashed curve).